(12) UK Patent Application (19) GB (11) 2 256 410 (13) A

(43) Date of A publication 09.12.1992

(21) Application No 9119354.0

(22) Date of filing 10.09.1991

(30) Priority data
(31) 9111851 (32) 03.06.1991 (33) GB

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(51) INT CL^5
B63H 1/04 25/40

(52) UK CL (Edition K)
B7V VBJ VBX

(56) Documents cited
None

(58) Field of search
UK CL (Edition K) **B7V VAA VBE VBJ VBX VCA V125**
INT CL^5 **B63H 1/00 1/02 1/04 25/40**
On-line database: W.P.I.

(54) **A marine propulsion system**

(57) A cylindrical rotor (10) mounted on a drive shaft (12) is driven by a reversible motor (20) within the hull; a pair of jets or nozzles (22, 24), preferably a plurality arranged along the rotor, are positioned on each side of the rotor and arranged to direct water from a pump or turbine (34) across the front and rear faces of the rotor so as to generate a propulsive "Magnus effect" when the rotor turns. For providing sideways motion for steering, a further set of jets (40, 42) are placed adjacent to the rotor.

A pair of propulsion units (rotor and jets) can be located port and starboard each in a narrow sharp-edged trough in the aft quarter side of the vessel (Figs. 19–20).

A submarine (Fig. 12) can have one or more rotor on a horizontal axis, for use in lift or diving. An oil rig semi-submersible platform (Figs. 10–11) has 4 or more units fitted to its hull.

Fig. 4.

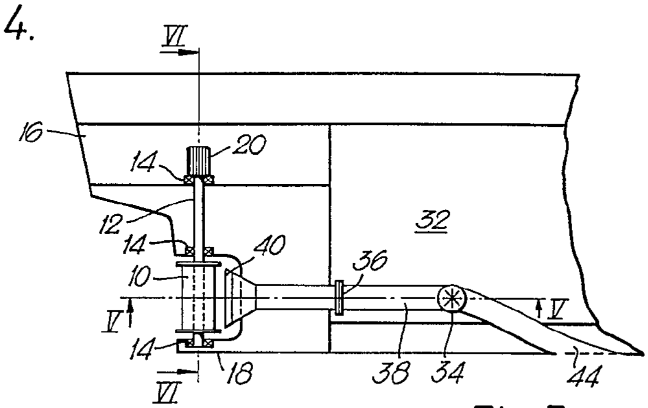
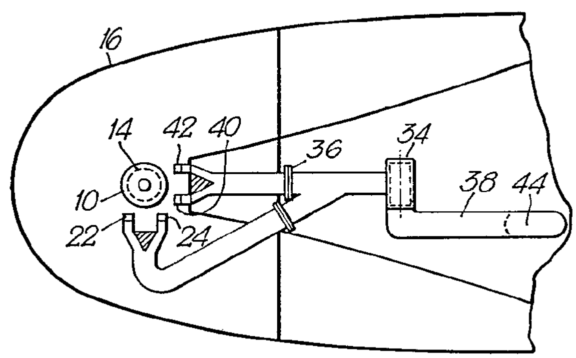


Fig. 5.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

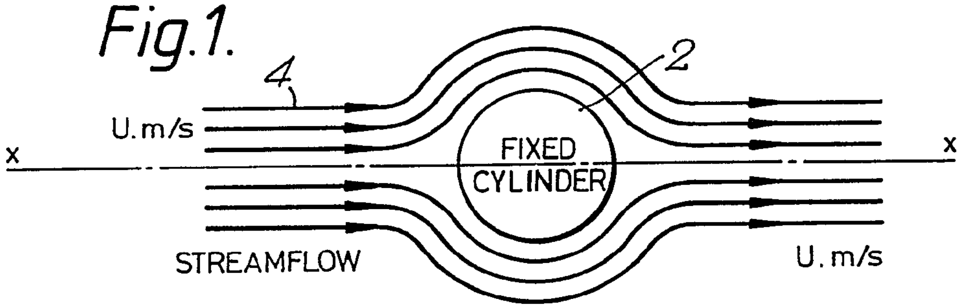


Fig.2.

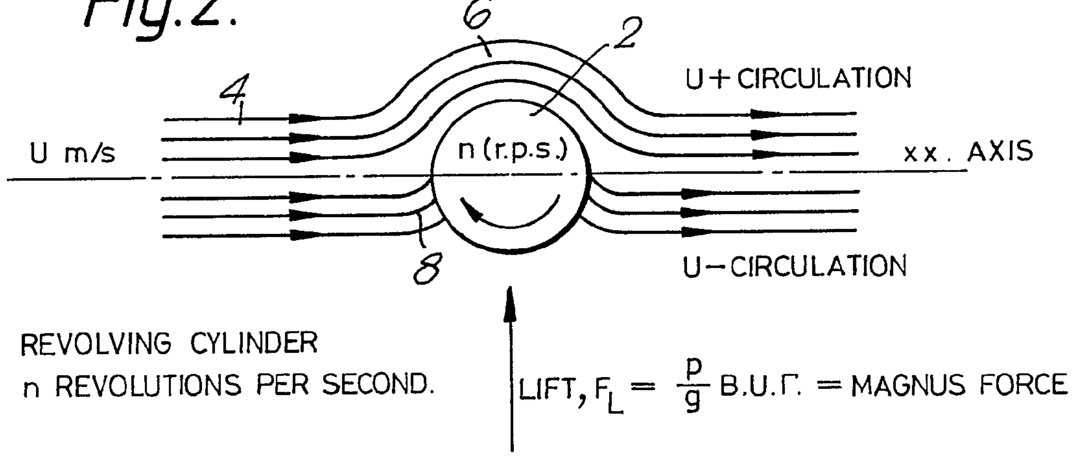


Fig.3.

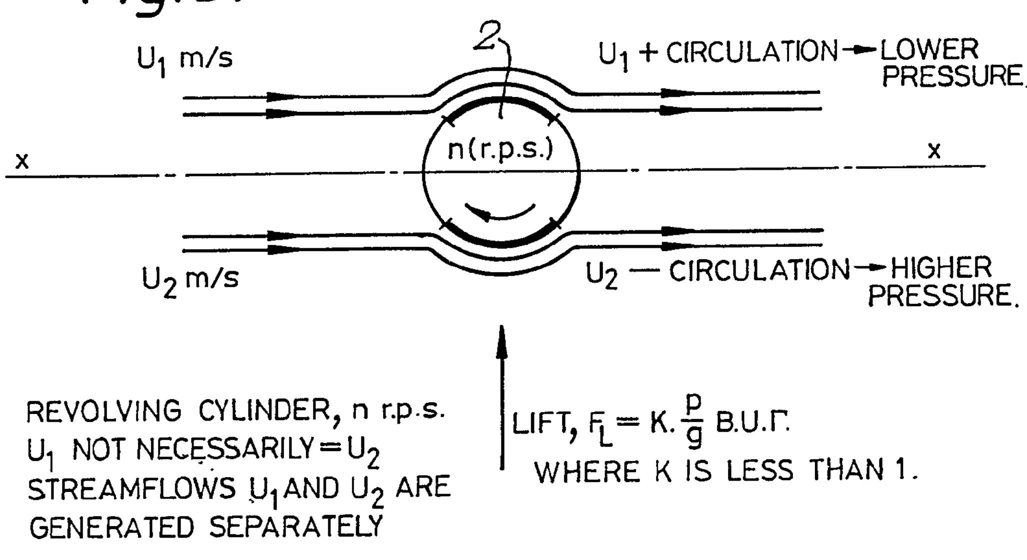


Fig. 4.

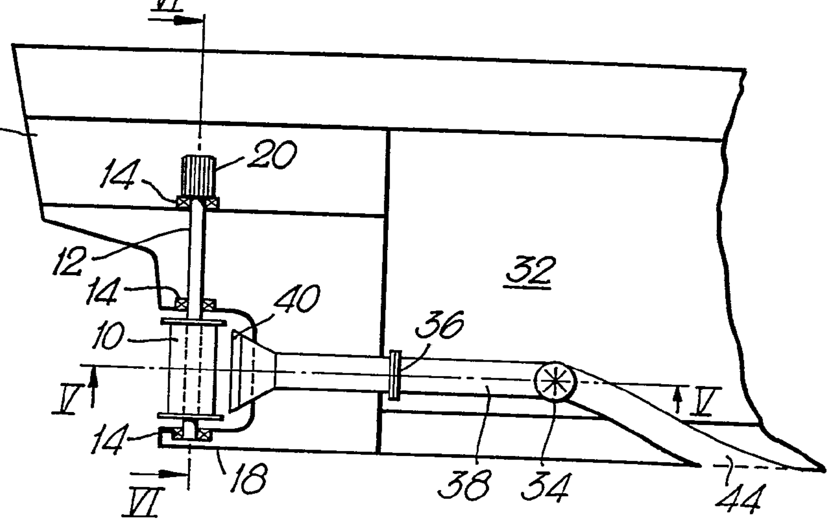


Fig.5.

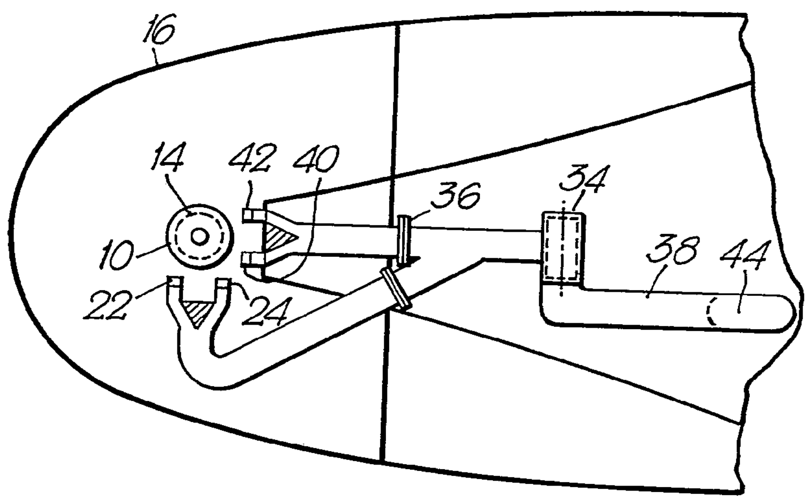


Fig. 6.

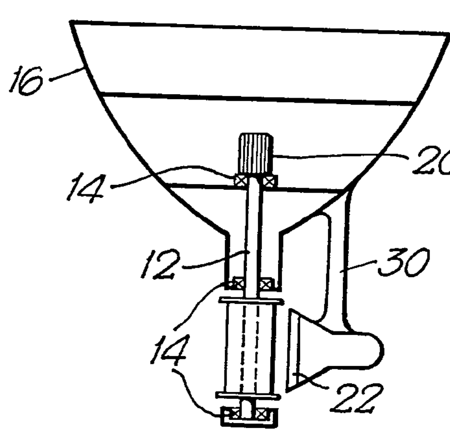


Fig.7.

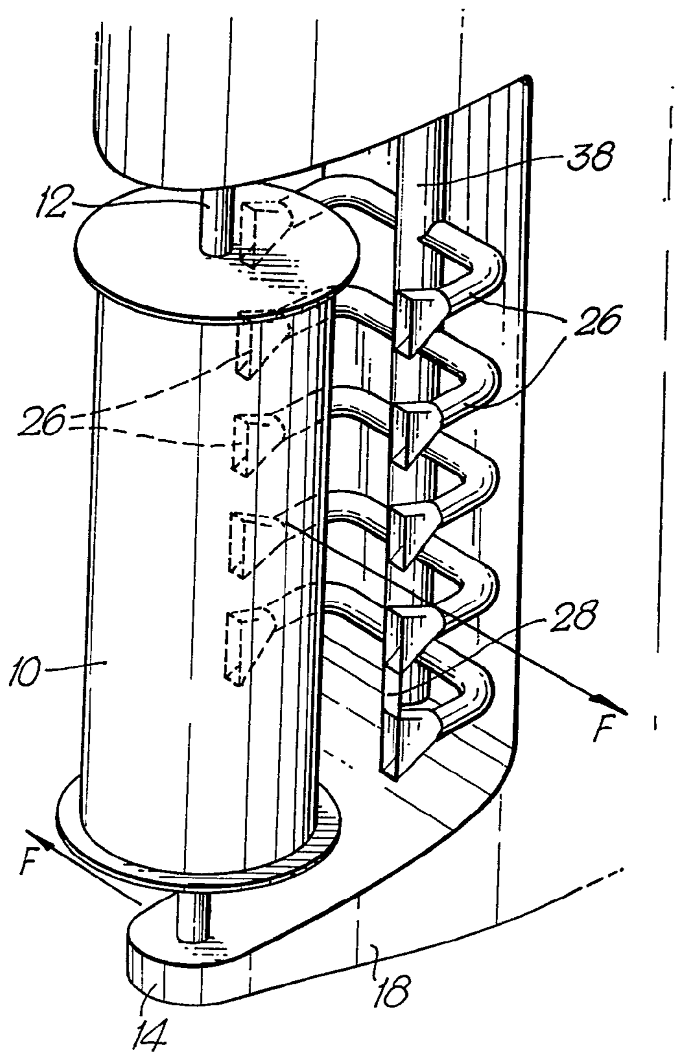


Fig.8.

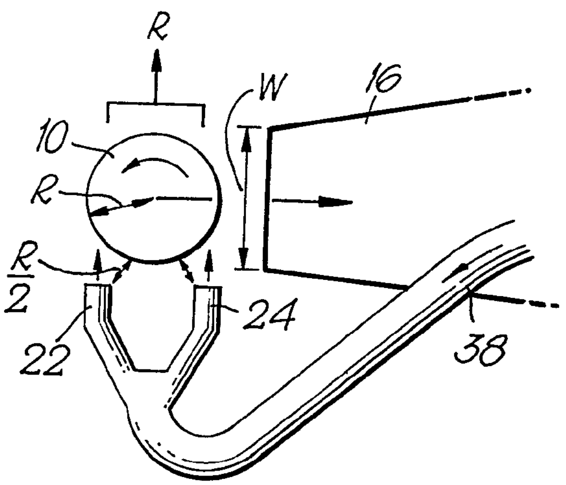


Fig.9.

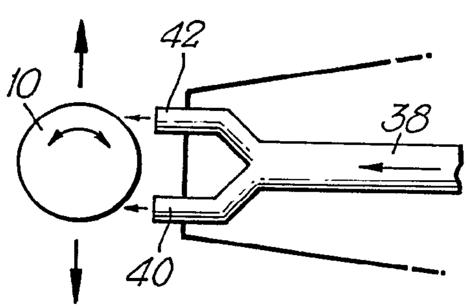


Fig.10.

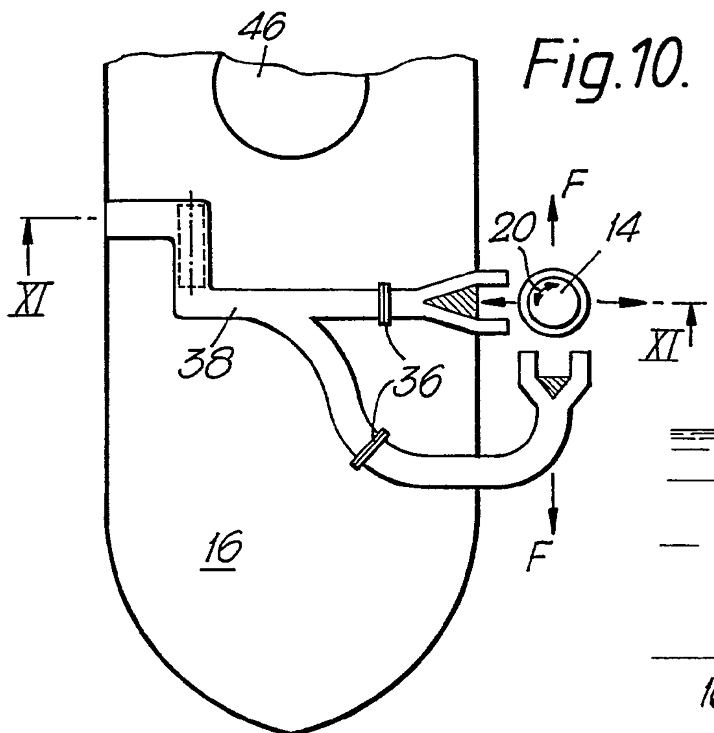


Fig.11.

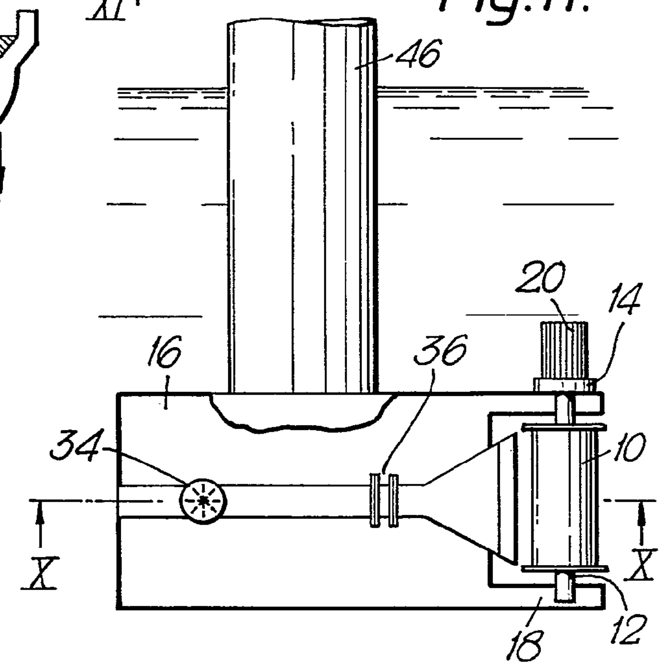


Fig.13.

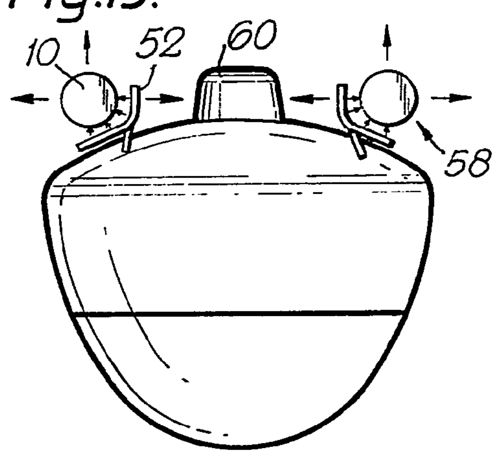


Fig.12.

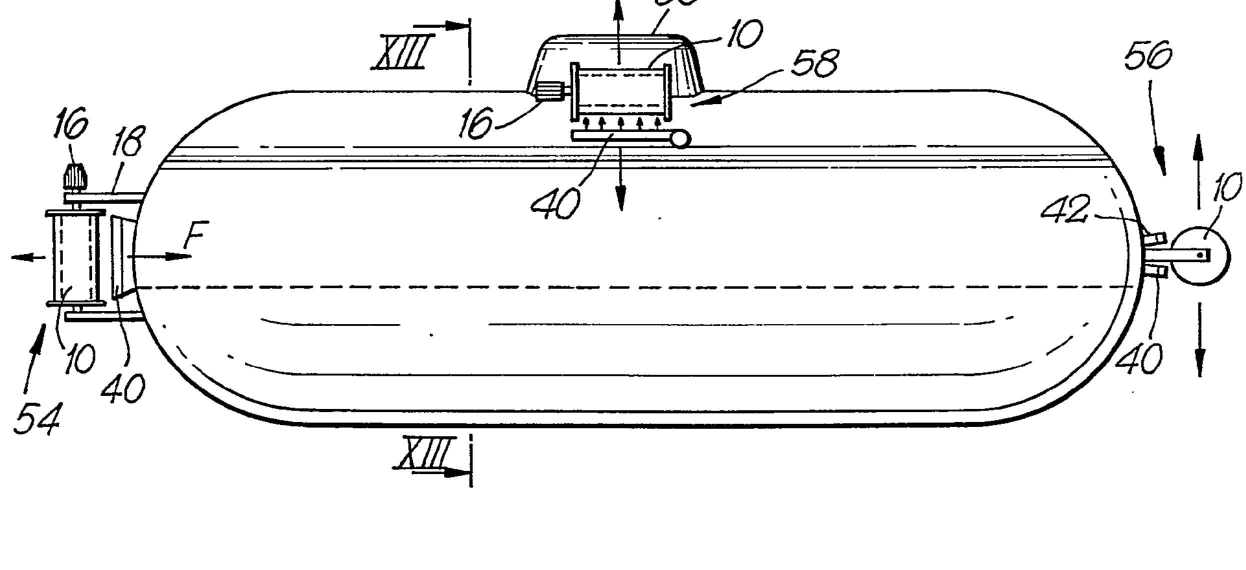


Fig.14.

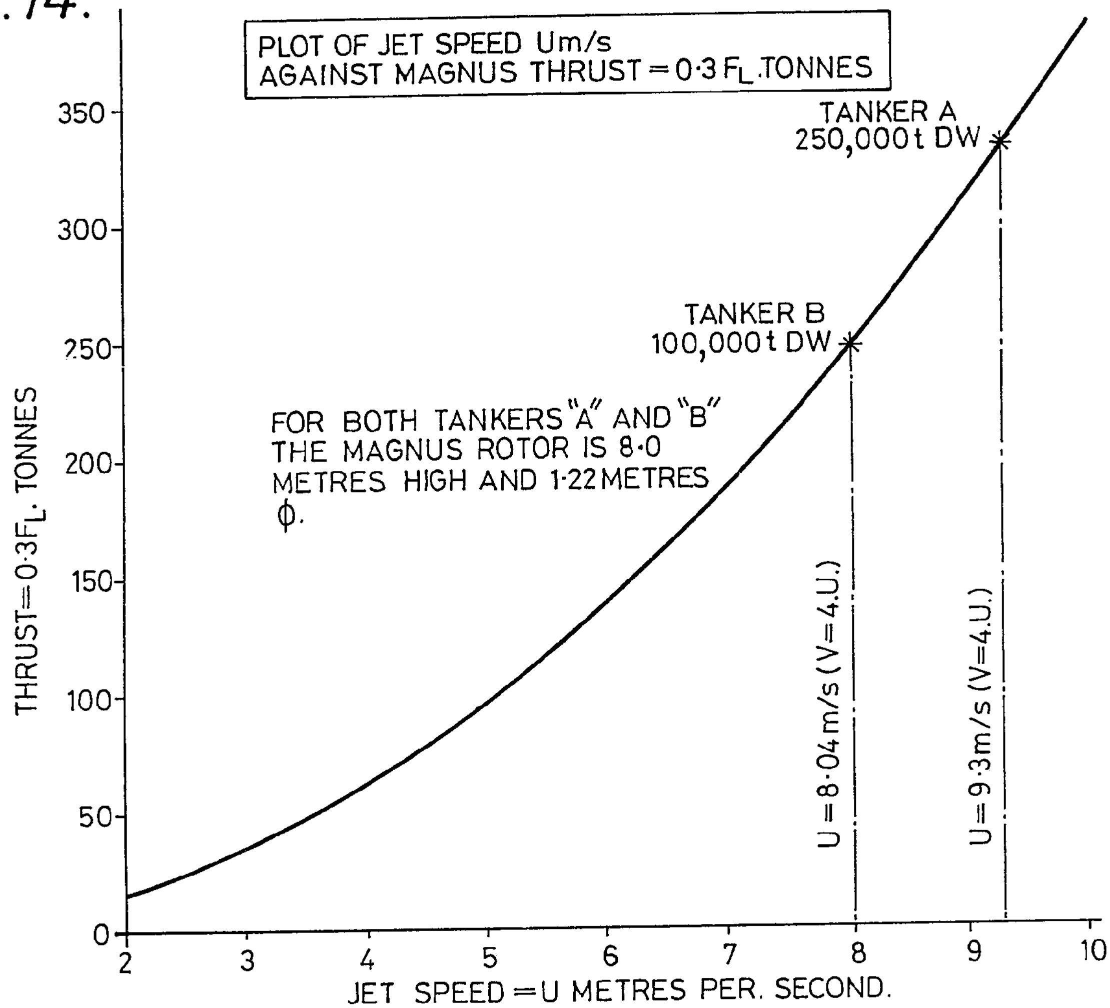


Fig.15.

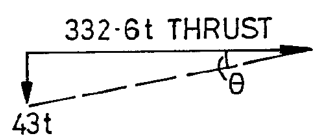


Fig.16.

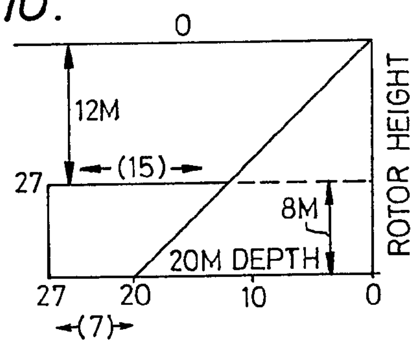


Fig.18.

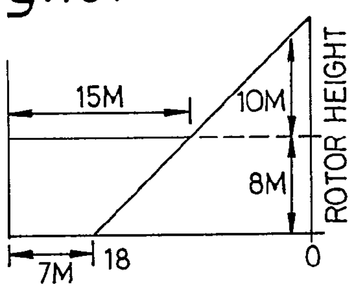


Fig.17.

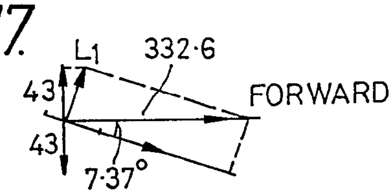


Fig. 19.

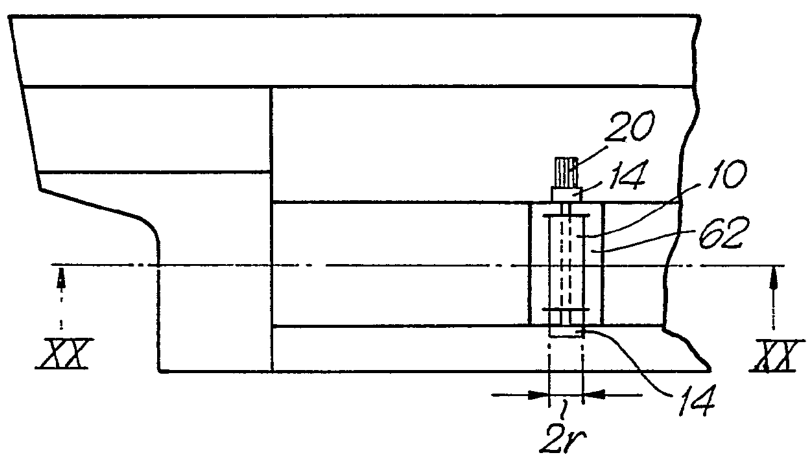
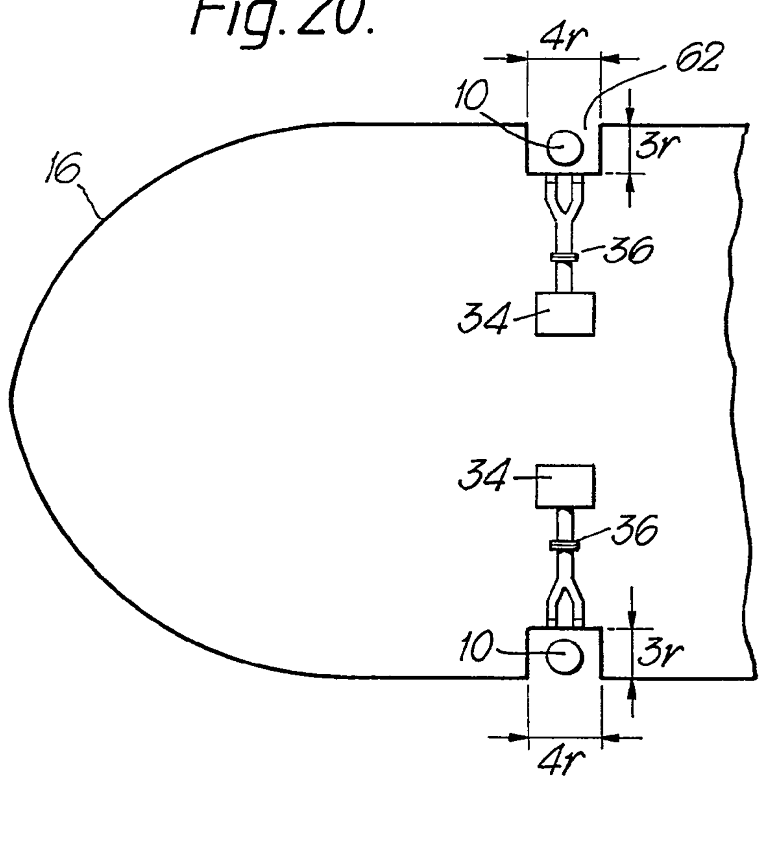


Fig. 20.



A MARINE PROPULSION SYSTEM

This invention relates to a machine for the propulsion, manoevering and dynamic positioning of ships and other marine and sub-sea vehicles.

The invention is based on the "Magnus effect", first observed by Professor Magnus of Berlin in 1852. An early successful use of this effect was by Dr Flettner in 1925 when his wind-propelled rotor ship made several crossings of the Atlantic Ocean; the ship had three vertical cylinders, each of height 17.0 metres, diameter 4.0 metres, located on the weather deck, and rotated by electric motors, so as to generate a "lift" or propulsive force within the atmospheric air streams, as a result of the Magnus effect.

The French marine explorer Cousteau has successfully tested ships with "turbo sails" during ocean crossings. He claimed that his system produced an energy saving of 35%, when used with a normal screw propulsion system; this energy saving is in agreement with the findings of Dr. Flettner.

Both these prior propulsion systems are however subject to the vagaries and randomness of the atmospheric wind conditions.

The object of the invention is to provide a novel marine propulsion system utilising the Magnus effect with the water in which the vessel is floating.

The Magnus effect is explained as follows:

Figure 1 of the drawings shows a stationary right circular cylinder or rotor 2 of radius R metres and length B metres, situated on the axis x-x of a uniform stream-flow 4 of a fluid having a velocity of U metres/second. If the cylinder is perfectly symmetrical then the uniform stream-flow remains symmetrical about the x-x axis, and there is no transverse pressure or force induced.

Figure 2 shows the same cylinder 2 rotated at <u>n</u> revolutions per second, within the same uniform stream, and it is apparent that a fluid circulation has developed within the flow, thus increasing the velocity of the upper stream-flow 6 and with consequent retardation of the lower stream-flow 8 velocity.

There is therefore a redistribution of the pressures within the stream, generating a cross-flow pressure of F_L kilograms, which according to the Kutta-Joukowski theorem has a magnitude:

$$F_L = \frac{p}{g}.B.U.\Gamma.\text{kilograms} \qquad \text{(i)}$$

where F_L = lift force in kilograms
p = specific weight of water kg/M^3
g = acceleration due to gravity - 9.81 M/s^2
B = length or height of the cylinder. Metres.
U = stream-flow uniform velocity M/s
Γ = circulation around cylinder M^2/s

Fig. 3 illustrates the action of a stream-flow as used in the Magnus effect upon the upper and lower segments of the revolving cylinder of Fig. 2. The stream-flow U_1 does not necessarily = U_2 and the streams are generated from two separate sources. With such a system I have measured with air a Magnus lift force which varied between 30% and 50% of the theoretical value as calculated from the theorem (i).

Thus for this measured segmental Magnus force F_L, the formula (i) is modified by the inclusion of an efficiency constant K which gives:

$$F_L = K.\frac{p}{g}.B.U.\Gamma.\text{kilograms; for air } K=0.3 \qquad \text{(ii)}$$

Considering that the density of seawater is 820 times that of air, the seawater force F_L will be large, and of a magnitude suitable for the largest marine user, and I make use of water for this effect rather than air as hitherto.

According to the present invention I provide a propulsion machine which comprises a right rotor suspended rotatably between lubricated bearings, and associated with two sets of crossflow channels or pipes each terminating in a jet nozzle adjacent to an opposite segment of the circumference of the rotor and each adapted to deliver a jet of liquid adjacent to said segments of the rotor, a driving motor for the rotor intended to be mounted within a marine vessel, and means for securing the rotor to the hull of the vessel.

A pump for the jets is required within the vessel.

The rotor is suitably of steel or other non-corrosive material, connected rigidly to the shaft, e.g. by discs at the top and bottom of the rotor.

The jets are positioned to direct a sheet of water to the two sides of the rotor; a series of jets can be used or more preferably two continuous elongated nozzles each extending the height of the rotor. Because of the reaction on the hull of a single stern-mounted propulsion machine, there is a deviation in the resultant thrust which needs to be rectified by adjusting the angle of the jets in relation to the hull (as seen in plan) by about 7°. Preferably each rotor has a second set of jets, for alternative use to steer the vessel, i.e. to give a sideways thrust.

For a submarine vessel, one propulsion machine can be fixed with its axis horizontally, to give up/down movement.

The invention will be further described with reference to the accompanying drawings, wherein:

Figs. 1, 2 and 3 are diagrams showing in plan, in a stream of fluid, a rotor which is stationary or revolving, so as to illustrate the Magnus effect;

Fig. 4 is a side elevation, partly in vertical section, of a propulsion machine of the invention fitted to the stern of a ship and Figs. 5 and 6 are respectively a horizontal section on line v-v and a front elevation, partly in section on line vi-vi of Fig. 4;

Fig. 7 is an enlarged perspective view from above and front of parts of the propulsion unit of Figs. 4 to 6;

Figs. 8 and 9 are enlarged fragmentary views of part of Fig. 5 showing respectively forward and sideways operation of the vessel;

Fig. 10 is a plan view, partly in section, of the front of a hull of a semi-submersible off-shore platform fitted with a propulsion unit of the invention, and Fig. 11 is a vertical section of the hull and part of a leg of the structure of Fig. 10;

Fig. 12 is a side elevation of a submarine showing propulsion units of the invention fitted fore and aft and one of two units on top, and Fig. 13 is a section on line xiii-xiii of Fig. 11 through the submarine;

Fig. 14 is a graph of the speed of the water jets used in the invention against the resultant thrust developed by the machine on tankers;

Figs. 15 to 18 are graphical illustrations of calculations of the efficiency of the propulsion of a tanker; and

Figs. 19 and 20 are respectively a side elevation and horizontal section on xx-xx of the rear part of a ship showing a different arrangement of two machines of the invention.

Referring to Figs. 4 to 7, a rotor 10 is supported on a drive shaft 12 upon three bearings 14 which are located within the hull 16 of a vessel or in an extension 18 below the hull, and a driving motor 20 is arranged to turn the shaft and rotor.

A jet system comprises at least one pair of jets or nozzles 22, 24 arranged to direct water across opposed front and rear faces of the rotor, as indicated in Figs. 5 and 8; there may be a series of such jets arranged in a vertical line as shown at 26 in Fig. 7 or they may most preferably be joined into one elongated nozzle 28. The apertures of the jet, of whatever configuration, are preferably located a distance from the rotor of half the rotor radius R, as shown in Fig. 8, and the width W of the portion 30 at the stern of the vessel is preferably, for a large ship, the same as the diameter of the rotor (see Fig. 8) so as to deflect the forward slipstream clear of the rotor 10. The jets used for forward (or reverse, since the motor 20 is reversible) propulsion are supported by suitable means such as a strut 30 (Fig. 6, 7) from the underside of the hull, and are located to the side of the rotor (Figs. 5, 8).

Suitable means (not shown) are provided to control the speed and direction of rotation of the drive motor 20 and the pump 34 and valves 36 for the jets.

For sideways operation to steer the vessel, a further set of jets 40, 42 are provided which are placed forward to the rotor at the stern, as shown in Figs. 5 and 8.

Within the machine room 32 is a pump 34 (or pumps) and valves 36 in a pipeline 38 which feeds the jets 22, 24 and takes in water from a port 44 located below the water line, e.g. centrally beneath the hull or preferably as shown, ——————————

off centre so as not to be blocked if the vessel is grounded.

Figs. 10 and 11 show one hull 16 and part of the leg 46 of a semi-submersible platform, e.g. for an oil rig; the two pairs of jets 48, 50 and reversible rotor 10 allow movement in any direction. The platform would have four or more of such propulsion units fitted to its hulls.

In Figs. 12 and 13, a submarine is shown which has external racks 52 for carrying cargo, e.g. of pipes; the lower part of the hull can be filled with water as ballast. The propulsion unit 54 at the stern is for fore and aft propulsion, unit 56 at the bows for lift and diving, and the units 58 on top, on each side of the conning tower 60, are for lateral (port/starboard) movement. The driving units 16 are water turbines.

Such a submarine could have a length of 33 m, breadth 11 m, depth 10 m, load draft 7 m, cargo deadweight of 150 tonnes maximum, operational depth of 300 m, and speed of 10 knots.

Large ships as shown in Figs. 3 to 9 could have propulsion units equivalent to a 10 metre propellor for a large tanker carrying a 250,000 tonnes cargo.

In use of any of these embodiments, each rotor 10 is rotated by the drive motor 16, e.g. driven by a diesel engine or alternator in a desired direction, the pump 34 is operated at pressures up to 4 kg/cm² and a selected valve 36 is opened so that parallel streams of water pass the rotor and a thrust F_L is generated, as shown by the heavy arrows in Figs. 4 to 12. To alter speed or course the direction of the rotor and/or the amount of water flow or the jets in use are altered appropriately. By reversing the rotor the thrust direction is reversed. The thrust is always at 90° to the plane of the streams of water.

By way of example, calculations are now presented of the power needed for two large tankers 'A' and 'B' of the following characteristics ("s.h.p" means "shaft horse power):

Tanker:	A	B
Displacement =	330,000 tonnes	140,000 tonnes
Oil Deadweight =	250,000 tonnes	100,000 tonnes
Propulsive power =	27,000 s.h.p	20,000 s.h.p
Maximum speed at full power, rough hull, rough weather =	15 knots	15 knots

For Tanker A:

$$\text{Resistance } R = \frac{\text{Power}}{\text{Speed}} = \frac{27000 \times 550}{15 \times 1.689 \times 2240 \times 0.9842} = 265.9 \text{ tonnes}$$

Conventional Propeller Thrust $T=1.25\,.R=1.25 \times 265.9 = 332.4$ tonnes (iii)

For Tanker B:

$$R=\frac{\text{Power}}{\text{Speed}}=\frac{20000 \times 550}{15 \times 1.689 \times 2240 \times 0.9842} = 196.9 \text{ tonnes}$$

$T = 1.25\ R = 1.25 \times 196.9 = 246.1$ tonnes (iv)

These calculated propeller thrusts, T, will be compared to the corresponding thrust, F_L, as developed from the rotor. The propulsion unit of the invention is positioned as in Figs. 8 and 9. The rotor 10 is a right vertical cylinder of height B = 8 metres and radius R = 0.61 metres.

The jet flow system has a speed of u metres/second. The circumferential speed of the rotor will be V m/s= 4u maximum.

Table 1

Jet speed u (m/s)	2	4	6	8	10
cylinder speed v (m/s)	8	16	24	32	40
$N=\frac{60v}{2\pi r}= 15.655\ V$ r.p.m.	125	250	376	501	626
circulation $\Gamma = 2\pi r V$ $m^2/s = 3.833V$	30.66	61.33	92.0	122.66	153.3
$0.3\ F_L=\frac{\rho}{g}\cdot B.u\,\Gamma \times 0.3$					
$0.3\ F_L=\frac{1.025}{9.81} B.u.\Gamma.0.3$ tonnes	15.38	61.5	138.4	246.1	384.4

The final line of the Table 1 gives the thrusts expected.

The use of the conservative thrust factor of 0.3 has been explained above.

The following calculation relates to the graph of Fig. 14:

Tanker A

$u = 9.3$ m/s (V= 4u, maximum)

$v = 37.2$ m/s $= 15.655 \times 37.2 = 582$ r.p.m

$\Gamma = 3.833\ v = 142.6\ m^2/s$

$0.3F_L = 0.25076\ u.\Gamma = 332.6$ tonnes (from (iii) above) T = 332.4 tonnes)

Tanker B

$u = 8.04$ m/s (V= 4u maximum)

$V = 32.16$ m/s $= 15.655 \times 32.16 = 503$ r.p.m.

$\Gamma = 3.833\ V = 123.27\ m^2/s$

$0.3\ F_L = 0.25076\ u\Gamma = 248.5$ tonnes (from (iv above) T = 246.1 tonnes)

For both tankers, jet area $= 40\%$ of cylinder profile

$$= 0.4 \times 1.22 \times 8.0$$
$$= 3.904\ m^2$$

Tanker A: for u= 9.3 m/s from Fig. 14:

$Q = u.A. = 9.3 \times 3.904 = 36.307\ m^3/s$ h= 27 metres

$$\text{Power} = \frac{pQh}{550\mu} = \frac{64 \times 36.307 \times 35.32 \times 27 \times 3.281}{550 \times 0.67} = 19{,}730 \text{ h.p}$$

Tanker B: for u= 8.04 m/s from Fig. 14:

$Q = u.A. = 8.04 \times 3.904 = 31.39\ m^3/s$ h = 25 metres

$$\text{Power} = \frac{pQh}{550\mu} = \frac{64 \times 31.39 \times 35.32 \times 25 \times 3.281}{550 \times 0.67} = 15{,}794 \text{ h.p.}$$

Tanker	A	B
Pump Power	19730 h.p	15794 h.p
Rotor Power	1000 h.p	1000 h.p
Total power =	20730 h.p (76.8%)	16794 h.p (84%)
Conventional power=	27000 h.p (100%)	20,000 h.p (100%)
Power saving =	23.2% (vi)	16% (vii)
Rotor Speed=	582.4 r.p.m	503.5 r.p.m.

Notes:

1. A pump efficiency of μ=0.67 is very conservative, but this low overall efficiency takes account of the balance of pipe friction/bend/exit losses.
2. It is likely that for Tanker 'B' a rotor shorter than 8 metres would have been more correct and more efficient.

Taking into consideration a gain in power efficiency it is envisaged that the single rotor at the stern will be arranged not only for forward and aft propulsion, but also for steering, without any fixed rudder.

In the forward propulsion mode, there is a jet reaction (see R in Fig. 8) which acts athwartships at the stern, and this reaction must be minimised, since it interferes with the steering of the ship.

Considering this problem for Tanker 'A', only, since this is the bigger ship (oil deadweight = 250,000 tonnes); taking a draft of 20 metres in association with a pumping head of h=27 M (see (iii) above):

Mean h = $\frac{1}{2}$ (15+7) = 11 m = 11 tonnes/m^2

F= P x A = 11 x 0.4 x 1.22 x 8 = 43 tonnes athwartships (see Figs. 15 and 16).

Tan θ = 43/332.6 = 0.1293

θ = 7.37°: for balance, the segmental jet unit has to be canted to 7.37° (see Fig. 17)

Loss 1. = L_1

= 43 tan 7.37° = 5.56 tonnes

Loss 2. = L2

= 332.6 cos 7.37° = (329.9 tonnes)

= 332.6 - 329.9 = 2.7 tonnes

total loss = 5.56 + 2.7 = 8.26 tonnes.

% reduction in thrust = $\frac{8.26 \times 100}{332.6}$ = 2.5%

Revision of above power savings (vi) and (vii):

Tanker 'A' - power saving = 23.2 - 2.5 = 20.7%

Tanker 'B' - power saving = 16.0 - 2.5 = 13.5%

The calculations are now corrected for variation in pressure head to show an efficiency gain.

<u>Tanker A</u> Draft = 20 m Pump power head = 27 m (see Fig. 16)

u = 9.3 m/s

Required velocity head = $\frac{u^2}{2g} = \frac{9.3^2}{2 \times 9.81}$ = 4.41 m

mean available velocity head = $\frac{1}{2}$ (15 + 7) = 11,

velocity head reduction = 11.0-4.41 = 6.59 m

minimum pump power = $\frac{\rho Q h}{550 \mu} = \frac{64 \times 36.307 \times 35.32 \times 20.41 \times 3.281}{550 \times 0.67}$ = 14914.0 h.p

for rotor = <u>1000 h.p</u>

Total power = 15914 h.p.

% power gain = $\frac{(27000 - 15914).100}{27000}$ = 41.0 - 2.5 = 38.5%

<u>Tanker B</u> Draft = 18 m Pump power head = 25 m (see Fig. 17)

u = 8.03 m

required velocity head = $\frac{8.03^2}{2 \times 9.81}$ = 3.29 m

mean available velocity head = $\frac{1}{2}$ (15 + 7) = 11.0 m

velocity head reduction = 11.0 - 3.29 = 7.71 m

reduced pump power head = 25.0 - 7.71

h = 17.29 m *

$$\text{minimum pump power} = \frac{\rho Q h}{550 y} = \frac{64 \times 31.39 \times 35.32 \times 17.29 \times 3.281}{550 \times 0.67} = 10923 \text{ h.p}$$

$$\text{for rotor} = \underline{1000 \text{ h.p}}$$
$$\text{Total power} = 11923 \text{ h.p}$$

$$\% \text{ gain in power} = \frac{(20000 - 11923).100}{20000} = 40.4\% - 2.5\% = 37.9\%$$

*Note: as indicated above, this head - 17.29 metres, suggests that the 8 metre height of the rotor could be reduced to about 7 metres for Tanker B.

These calculations indicate that the total power requirement for the system of the invention will be smaller than the power required for equivalent current screw propeller marine machinery systems. Taking into consideration the large proportion (=30%) of current marine power which is absorbed in "screwing" the propeller and adjacent water, this finding is not surprising.

Referring to Figs. 19-20, a pair of propulsion units are located port and starbord each in a vertical Prandtl slot 62 in the sides of the vessel, in which the rotors are thus protected. Suitable dimensions, as indicated in the drawing are that the depth of each slot is 3r (where r is the radius of the rotor), and its width is 4r; a rotor of height 5 metres can be fitted into a slot 6 m high.

A Prandtl slot is a narrow, sharp-edged trough in a surface across which fluid is flowing - see Prandtl, " The Physics of Solids and Fluids, London, 1930, p 228 or S. Goldstein (editor), Modern Developments in Fluid Dynamics, 1965, Vol I, p 88.

This embodiment has the following advantages and features:

As indicated above, a single stern rotor arrangement is subject to a deviation reaction of up to 7°, also a centre line jet flow unit is required. The twin rotor propulsion system in Prandtl slots has no deviation reaction and also obviates the requirement for a centre line jet

flow system at the stern.

Based upon the same conditions of calculation as above the following is a comparison between single rotor and twin rotor propulsion for Tankers A and B:

	Tanker A	Tanker B
Shaft horse power (screw prop)	27,000	20,000
Thrust tonnes	332	246
Single rotor	B=8m r=0.61m	B=8m r=0.61m
Total pump power	15,914	11923
Twin rotors	2@B=5m 4=0.54m	2@B=5m r=0.54m
Total pump power	16,840	12,245
Thrust tonnes	2 x 166	2 x 123

On a basis of identity of thrust both rotor propulsion systems of the invention show large power savings, with the twin rotor propulsion system having a maximum possibility for increased safety redundancy on all types of ships. The invention can provide the following advantages:

- a reduction in hull vibration levels;
- an overall power reduction compared with present systems (the screw propeller);
- an improvement in the safety redundancy of the propulsion and machinery, particularly where large ships are concerned;
- superior manoevering and control of ships at all speeds, (turning at low forward speeds, immediate reverse stopping);
- enhancement of the safety of ships which carry pollutants, chemicals or other dangerous goods;

- the use of two propulsion units provides very superior safety redundancy; and
- in an aground situation with the astern rotor still immersed, the ship can have 100% astern thrust; and
- a propulsion unit at the bow would improve safety redundancy and manoevering.

CLAIMS:

1. A propulsion machine which comprises a right rotor suspended rotatably between lubricated bearings, and associated with two sets of crossflow channels or pipes each terminating in a jet nozzle adjacent to an opposite segment of the circumference of the rotor and each adapted to deliver a jet of liquid adjacent to said segments of the rotor, a driving motor for the rotor intended to be mounted within a marine vessel, and means for securing the rotor to the hull of the vessel.

2. A propulsion machines as claimed in Claim 1, which includes a second set of said channels or pipes and nozzles adjacent to the said rotor but located at an angle with respect to the first set when viewed from the axis of rotation of the rotor, for use in moving the vessel in a different direction to that obtainable by said first set of nozzles.

3. A propulsion machines as claimed in Claim 1 or 2, which includes means for forcing liquid through said channels or pipes.

4. A propulsion machines as claimed in Claim 3, wherein said means is a pump or turbine.

5. A propulsion machine as claimed in any preceding claim which includes means for control of the speed and direction of rotation of said rotor and of the flow of the liquid to the rotor.

6. A propulsion machines as claimed in Claim 1 substantially as hereinbefore described with reference to any of Figs. 4 to 9, 10 and 11, 12 and 13 or 19 and 20 of the accompanying drawings.

7. A marine vessel or platform which incorporates at least one propulsion machine as claimed in any preceding claim.

8. A marine vessel as claimed in Claim 7, wherein a single rotor is mounted vertically at the stern of the vessel with the jet nozzles arranged to direct water across the front and rear faces of the rotor.

9. A marine vessel as claimed in Claim 7, wherein a pair of propulsion units are mounted vertically each in a slot in the aft quarter of sides of the hull of the vessel, the jet nozzles of each propulsion machine being arranged to direct water from within the vessel and across the front and rear faces of the respective rotor.

10. A method of propulsion of a marine vessel or platform wherein a machine as claimed in any of Claims 1 to 6 is used.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

9119354.0

Relevant Technical fields

(i) UK Cl (Edition K) B7V-VAA,VBE,VBJ,VBX,VCA,V125

(ii) Int Cl (Edition 5) B63H-1/00,1/02,1/04,25/40

Search Examiner

B F BAXTER

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI

Date of Search

22 NOVEMBER 1991

Documents considered relevant following a search in respect of claims 1-10

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

SF2(p)

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Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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